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ORIGINAL ARTICLE

A Method to Harness Maximum Power from Photovoltaic Power Generation Basing on Completely Mathematical Model

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Abstract: This paper introduces a new method that no previous study has been done in this photovoltaic power generation similar to this paper to harness maximum potential power from photovoltaic power generation. The completely mathematical model added the relation between diode factor of the generation and p-n junction temperature is proposed to use in this method. The maximum power point tracker combines the iterative and bisectional technique, the completely mathematical model of PVG and the system of equations that converts value of parameters from standard test condition to any working condition, measuring sensors to measure power of solar irradiance and p-n junction temperature to determine parameters at maximum power point at any working condition. The voltage controller is designed to drive this generation to expect working state to harness maximum power. An experimental model corresponding to this method was designed and operated in real conditions in Viet Nam. Experimental results show the high accuracy of analyzing in theory and high capability to bring this method out real applications to harness all available energy of this generation.

Keywords: *Bisectional technique, voltage controller, iterative technique, maximum power point, maximum power point tracker, completely mathematical model, photovoltaic power generation.*

I. INTRODUCTION

Photovoltaic power generation (PVG) has been harnessed in many different approaches. General blocks for systems harnessing PVG can be considered as power converters, maximum power point tracker (MPPT), controllers and energy storage (ES) or utility to extract maximum power from PVG. Although maximum power point (MPP) of PVG has been approached in many techniques, they can be still classified into online and offline groups [1], [2], [3].

Techniques such as Perturb and Observe (P&O), Incremental Conductance (INC) or Extremum Seeking Control (ESC),... are in the online group [1], [2], [3]. These techniques only give appraisements about MPPs out after being actively change control pulse for power converters to try the response of PVG [1], [2]. Due to only using voltage and current sensors with low cost and easy implementation, these techniques can be applied for any capacity of PVG without providing all parameters for controllers but the detective process causes power loss quite much and is easy to make wrong appraisements about MPP when power of solar irradiance (G), p-n junction temperature (T) or voltage at DCbus (v_{DCbus}) varies [2], [3], [4]. Because of these reasons, they can't be highly evaluated and applied in applications having high requirements.

Offline techniques such as Constant Voltage (CV), Temperature (Temp), Optimal Gradient (OG),... determine MPP basing on mathematical model of PVG [2], [3], [4], [5]. They have appraisements about MPPs before sending control pulse to power converters. To decrease power loss caused by control process, these techniques must be used adequate information about implemented structure and mathematical model of PVG, value of (G, T). It means that controllers are only designed for each system. To have information about G and T, it must be correctly implemented sensors or chosen right type of sensors that has a suitable range of wavelength corresponding to type of PVG. Recently, some manufacturers have produced pyranometers (PYR) such as PYR-BTA (a production of Vernier) that can measure G and be quite suitable for PVG produced from semiconductors.

Moreover, value of temperature at back of the panel is quite stable and the nearest value of p-n junction temperature so this is the the best place to implement the temperature sensor (TempS). So, mathematical model is the biggest problem for offline techniques.

Almost previous studies have not any accurate evaluation about the relation between currently mathematical model and publications of manufacturers. It makes mathematical model of PVG not complete and techniques to determine MPP basing on mathematical model haven't applied widely.

Recently, the mathematical model was added the relation between diode factor (n) and T. So, the completely mathematical model corresponding to the single-diode model includes series resistor (R_S), parallel resistor (R_p), reversed saturation current (I_0), photo-generated current (I_{ph}), thermal voltage (V_t), relation between n and T, open-circuit voltage (V_{OC}), short-circuit current (I_{SC}). Value of almost above parameters is often published by manufacturers or determined by mathematical tools in standard test condition (STC), that has $G=G_{stc}=1000$ W/m^2 and $T=T_{stc}=25^0$C. They also change corresponding to the variation of (G, T) in real working conditions and can be determined the rule of variation in laboratories [1].

Moreover, the iterative and bisectional (IB) technique was proposed recently and used in MPPT to determine voltage (V_{mpp}) and power (P_{mpp}) at MPP [1], [2]. V_{mpp} is set as a reference value to drive current state to expected state (at MPP). P_{mpp} is used to test the coincidence of power (p_{pv}) generating from PVG and P_{mpp}. The IB technique is considered as the best way to calculate parameters at MPP faster and can be applied in any structure of PVG [1], [2].

This paper will present a method to harness energy from PVG basing on its completely mathematical model. Section II will introduce the general structure of the system, the IB algorithm to determine parameters at MPP, system of equations to convert value of parameters from STC to any working condition and control strategy for this structure. Section III will introduce an experimental system using commercialized devices such as SV-55 panel, PYR-BTA and LM-35. Experimental results will be represented in section IV. Conclusions and next research problem will be shown in section V.

II. METHOD TO HARNESS POWER AT MAXIMUM POWER POINT USING THE IB TECHNIQUE

2.1 General structure of the system

To execute the purpose of harnessing all available maximum energy from PVG (power at MPP), output terminals of PVG must be connected to a DC/DC converter and an energy storage (ES) having large capacity to absolutely absorb power from PVG [6], [7], [8]. The general structure of the system is depicted in Fig. 1.

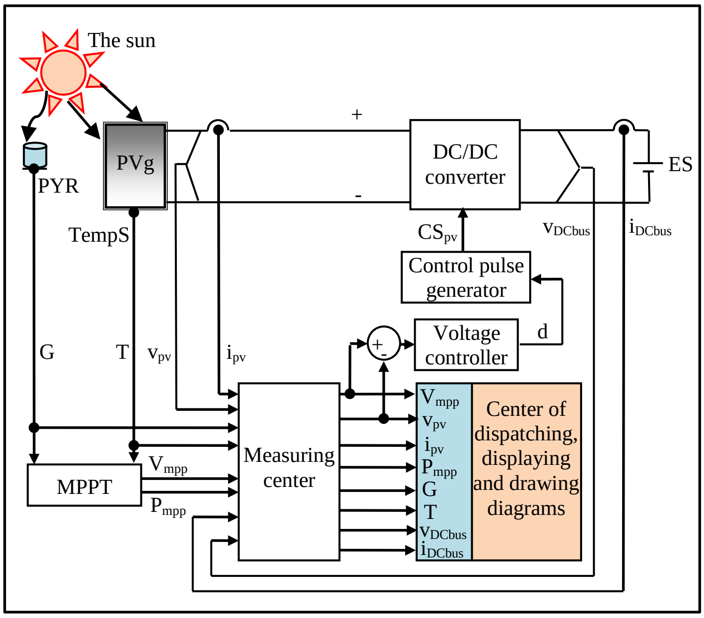


Fig. 1. General structure of the system

Measuring center collects value of all information provided by sensors to dispatch and draw diagrams, including:

- Instantaneous currents: i_{pv} at the output terminals of PVG and i_{DCbus} at the output terminals of the DC/DC converter from current sensors.
- Instantaneous voltages: v_{pv} at the output terminals of PVG and v_{DCbus} at DCbus from voltage sensors.
- Instantaneous value of G from a PYR and T from a TempS.

The combination of the measured information about (G, T) and the completely mathematical model of PVG helps the IB technique in MPPT calculate parameters at MPP accurately. The controller compares instantaneous value of v_{pv} and V_{mpp} to decide a suitable control pulse before sending it to the control pulse generator.

The DC/DC converter is used an adjustable block to regulate electrical load for PVG that is suitable to the available maximum power at the considered time (power at MPP).

Voltage at DCbus must be held at a constant value so it has a big capacity that can absolutely absorb power from the DC/DC converter and its voltage isn't affected much by charging current.

Center of dispatching, displaying and drawing diagrams sets working mode up, collects and displays value of all instantaneous information measured by sensors, draws diagrams as required in computer software of management and control.

2.2 MPPT basing on completely mathematical model

The IB technique uses the detective technique to determine pair-values of (v_{pv}, i_{pv}) and bisectional technique to reduce the volume of calculation process in the processor. The IB algorithm is depicted in Fig. 2 [1], [2].

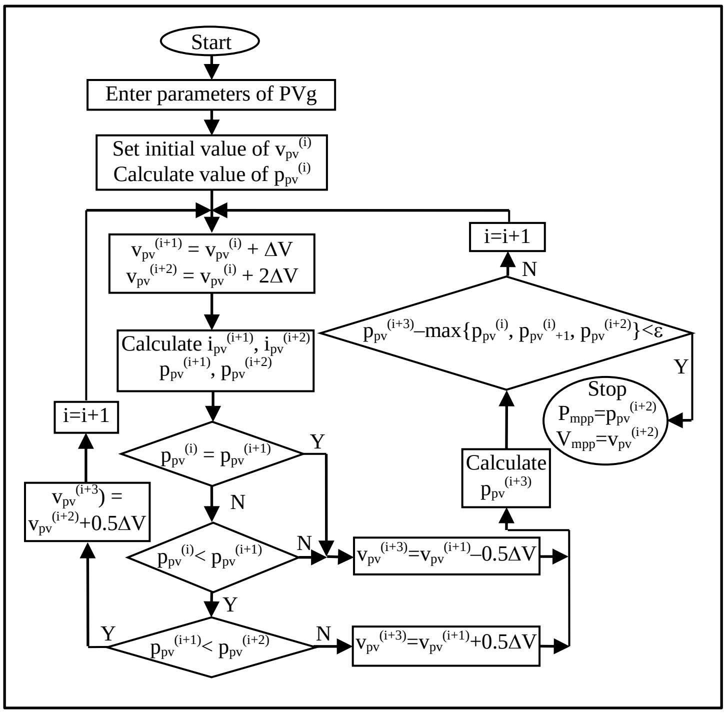


Fig. 2. MPPT basing on the completely mathematical model

In the process of real operation, parameters in the mathematical model of PVG always change corresponding to the variation of (G, T), where range of G is from 0 to 1000 W/m^2 and range of T is from about 10^{0}C to 70^{0}C in Viet Nam. It makes v_{pv}-i_{pv} and v_{pv}-p_{pv} curves vary and MPPs move continuously corresponding to working conditions. The variation of parameters is represented by (1) [1], [2]:

$$\begin{cases} I_{ph}\big|_{G,T} = \dfrac{G}{G_{stc}}\{I_{phstd}[1 + C_{TI}(T - T_{stc})]\} \\ I_{SC}\big|_{G,T} = I_{SCstc}\left[\dfrac{G}{G_{stc}} + C_{TI}(T - T_{stc})\right] \\ V_t\big|_{G,T} = V_{tstc}\dfrac{T}{T_{stc}} \\ V_{OC}\big|_{G,T} = V_{OCstd}[1 + C_{TV}(T - T_{stc})] + V_t \ln\dfrac{G}{G_{stc}} \\ R_p\big|_{G,T} = R_{pstc}\dfrac{G_{stc}}{G} \\ R_S\big|_{G,T} = R_{Sstc} \end{cases} \quad (1)$$

where, values of symbols having "stc" are defined in STC.

System of equations (1) is used to determine the current state and helps to construct v_{pv}-i_{pv} and v_{pv}-p_{pv} curves. Considering a type of PVG, parameters of a SV-55 panel are represented in Table 1.

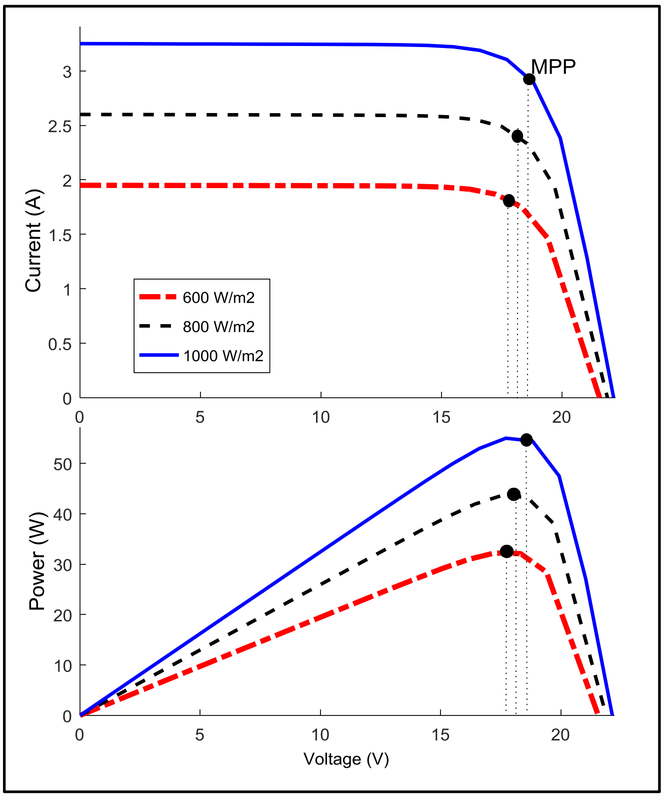
Table 1. Parameters of a SV-55 panel

Type of parameters	**Value**
Short-circuit current (A)	3.25
Open-circuit voltage (V)	22.14
Voltage at MPP (V)	18.4
Current at MPP (A)	3.06
Temperature coefficient of I_{SC} (mA/^{0}C)	4.7
Temperature coefficient of V_{OC} (mV/^{0}C)	-0.743
Temperature coefficient of power (%/^{0}C)	-0.451
Photo-generated current (A)	3.2502
Reversed saturation current (A)	1.623x10^{-8}
Thermal voltage at p-n junction (V)	1.141
Series resistor (Ω)	0.151
Parallel resistor (Ω)	1675.9

The relation between n and T is represented in (2):

$$n(T) = 1 - \frac{91}{10000}(T - T_{stc}) + \frac{1}{20000}(T - T_{stc})^2 \quad (2)$$

v_{pv}-i_{pv} and v_{pv}-p_{pv} curves of the SV-55 panel in:
case 1 (G varies, T=T_{stc}) and
case 2 (T varies, G=G_{stc}) are shown in Fig. 3.



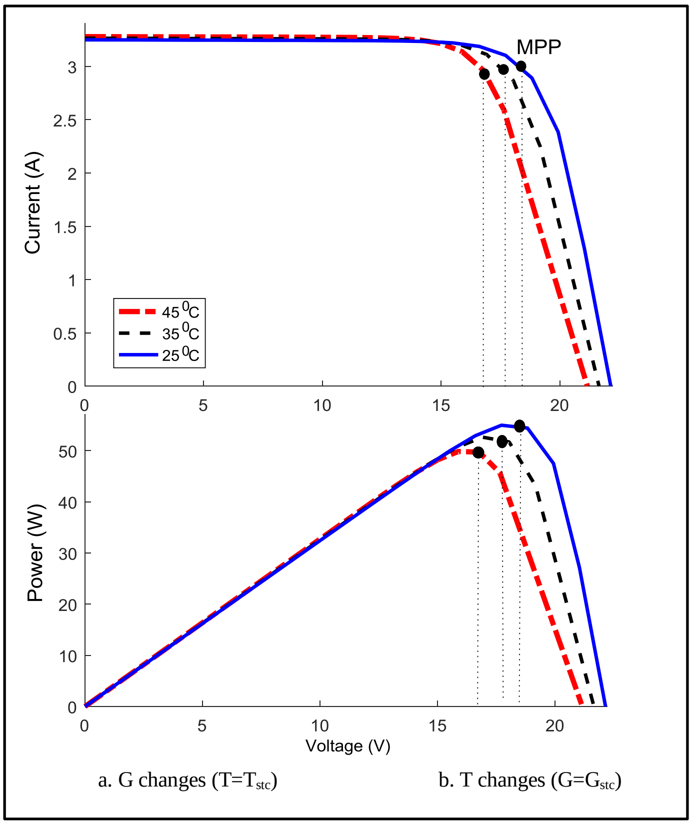


Fig. 3. v_{pv}-i_{pv}, v_{pv}-p_{pv} curves of the SV-55 panel in two cases

2.3 Control strategy for MPPT

Basing on measured and calculated information, a control strategy for this system to harness all maximum power from PVG is depicted in Fig. 4.

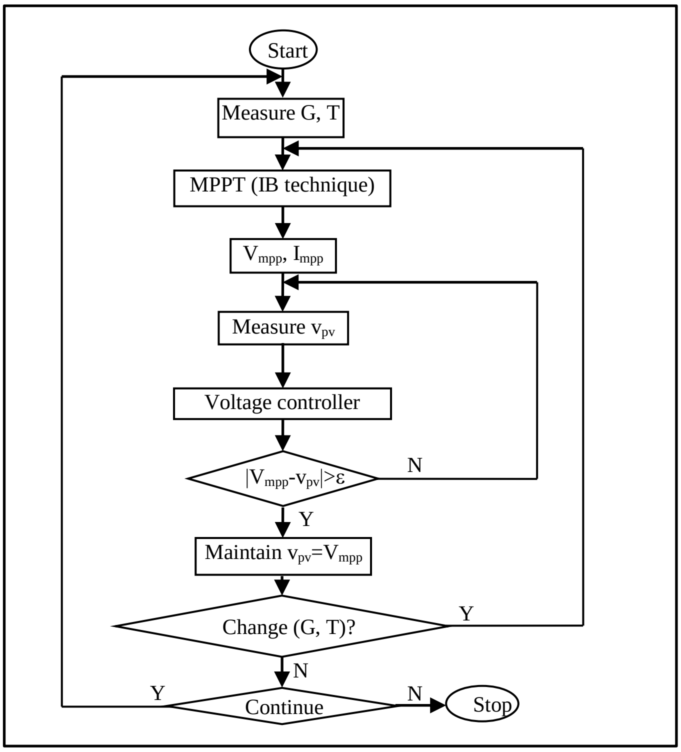


Fig. 4. Control strategy to harness MPP

III. EXPERIMENTAL SYSTEM

3.1 Implementation of the experimental system

Main blocks in the experimental system include:

- SV-55 panel, a production of Scott-Germany.
- PYR-BTA, a production of Verniner.

This device collects power of solar irradiance in visible and infrared wavelength as describing in Fig. 5. PYR-BTA is a new device produced some years recently and has a wave range that is suitable with PVG made from semiconductor [9].

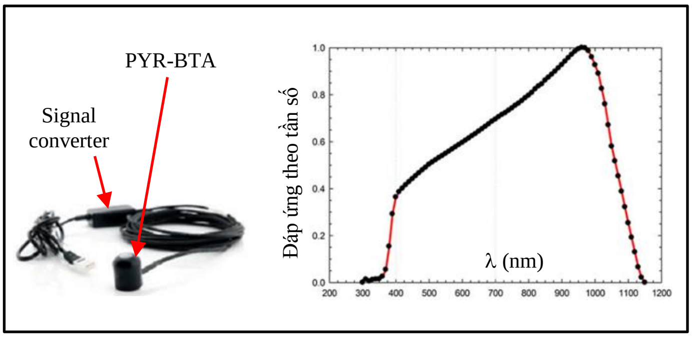


Fig. 5. PYR-BTA to measure G

The signal converter and cable are provided by Vernier to convert value of G to voltage signal. Output of the signal converter is from 0 to 5 V corresponding to G in range (0÷1000)W/m^2 (linear ratio 200 W/m^2 per V).

- A temperature sensor with high accuracy, LM-35, is used in linear ratio [10].
- A main board including a power circuit of DC/DC buck converter and a measuring circuit. Control center is ATMega328U microprocessor.
- A battery 12V-35Ah, a production of Dong Nai branch, is used as an ES.

Control strategy for the experimental system is shown in Fig. 6.

This strategy combines the control strategy described in Fig. 4 and the characteristic of battery. It has two charging modes. For the bulk charging mode, charging current can increase to a high value if it has much power from PVg delivered to DCbus and the capacity of the battery is smaller than 80% rated capacity. In the trickle charging mode, charging current is decreased to a small value to protect the battery.

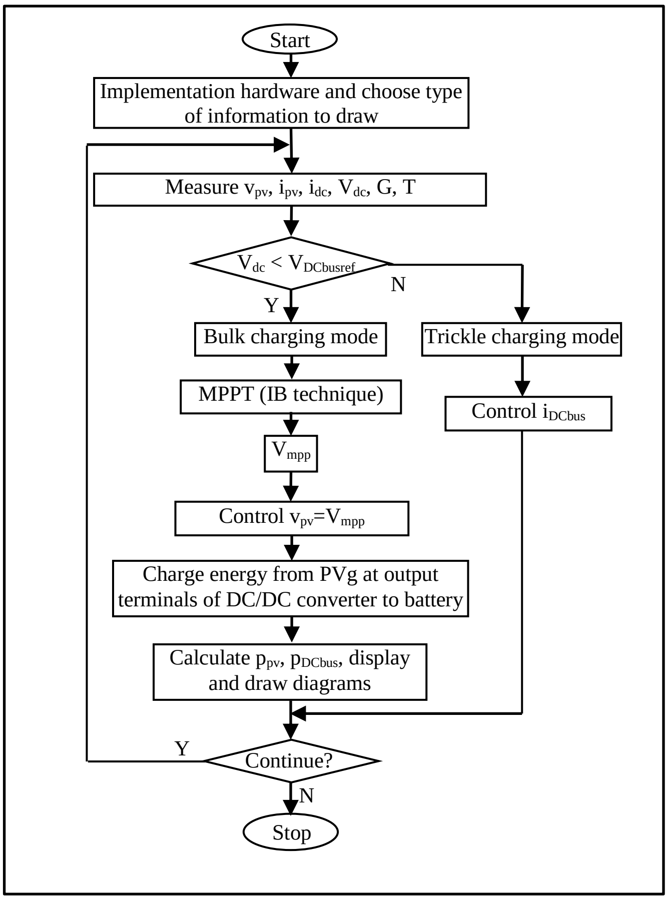


Fig. 6. Control strategy for experimental system

The power generating from PVG and delivering to the DCbus can be calculated by (3) and (4):

$$p_{pv} = v_{pv} i_{pv} \quad (3)$$

$$p_{DCbus} = v_{DCbus} i_{DCbus} \quad (4)$$

The implementation of above devices is represented in Fig. 7.

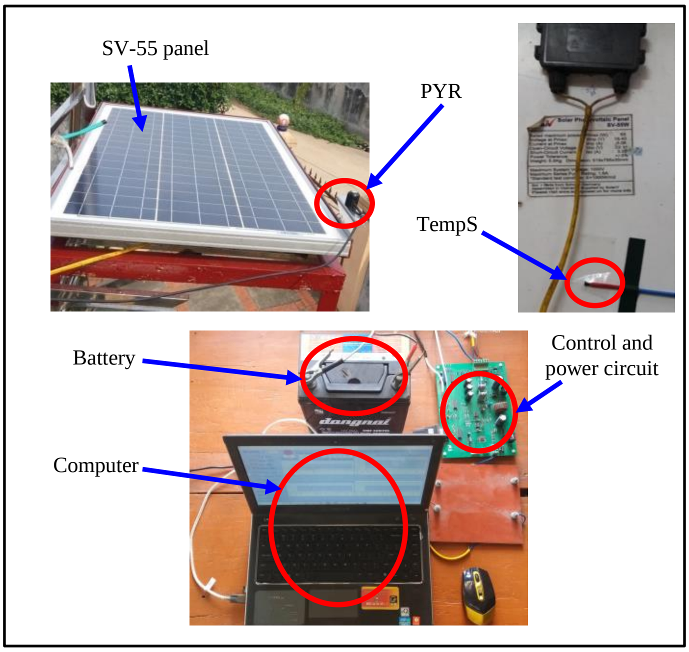


Fig. 7. Implementation of the experimental system

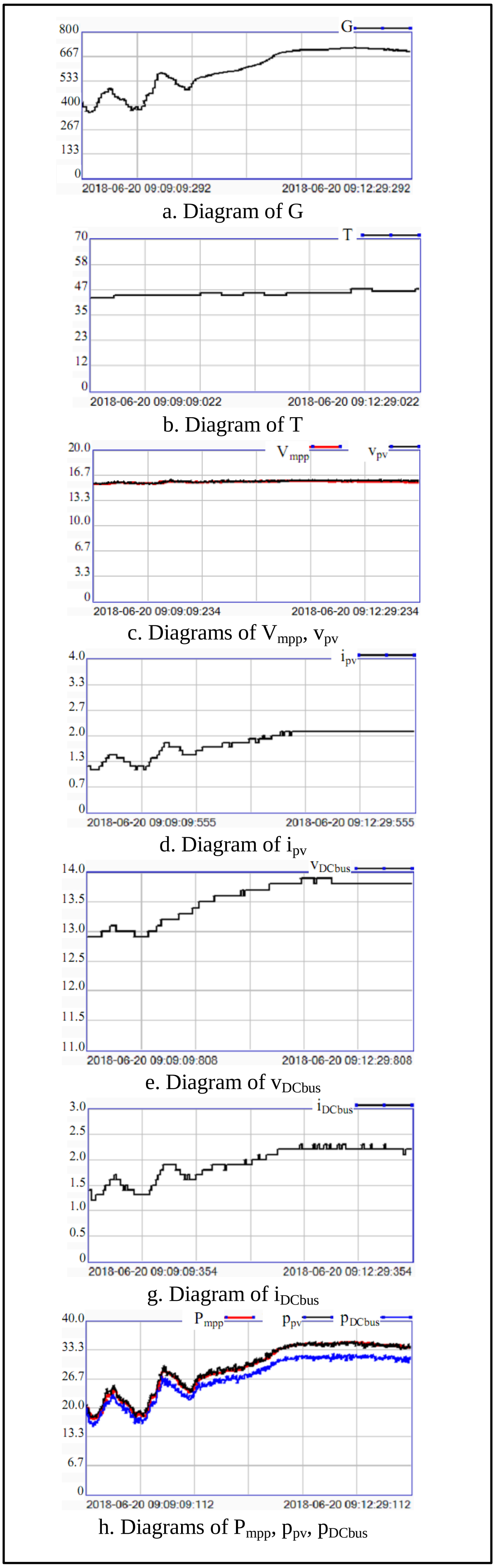
Management / control software is constructed basing on Kingview 6.5 software to observe instantaneous information and execute control command from computer. Measured information is executed in the circuit and transferred to computer by using RS232 communication protocol and USB-COM cable. The controller and type of data/diagrams can be set up or displayed in this management/control software to have experimental results as required.

IV. EXPERIENMENTAL RESULTS

Three experimental sample tests were executed in real conditions in Thai Nguyen province, Viet Nam. They were also random sample tests in 20 June 2018. The first one was taken from 9h09'09" to 9h12'29", the second sample was taken from 10h06'20" to 10h09'40" and the last sample was taken from 11h30'50" to 11h34'10". The management/control displays measured and calculated information, including G, T, v_{pv}, i_{pv}, v_{DCbus}, i_{DCbus}, P_{mpp}, p_{pv}, p_{DCbus}.

Experimental results corresponding to sample tests are represented in Fig. 8, Fig. 9, Fig. 10.

Experimental results show that G can vary continuously in wide range while T varies very slowly as depicted in Fig. 8ab, Fig. 9ab, Fig. 10ab. Whenever a new value of V_{mpp} is provided by MPPT, the voltage controller immediately changes the control pulse and drives voltage at the output terminals of PVG to V_{mpp} to have the coincidence as described in Fig. 8c, Fig. 9c, Fig. 10c. Because of the effect of voltage controller, the current at the ouput terminals of PVG also changes corresponding to the variation of (G, T) và v_{pv} as shown in Fig. 8d, Fig. 9d, Fig. 10d. Consequently, amount of power generating from PVG goes through the DC/DC buck converter, is delivered to DCbus and charges ES. Value of v_{DCbus} changes very slowly corresponding to the variation of i_{DCbus} as represented in examples in Fig. 8, Fig. 9, Fig. 10.



a. Diagram of G

b. Diagram of T

c. Diagrams of V_{mpp}, v_{pv}

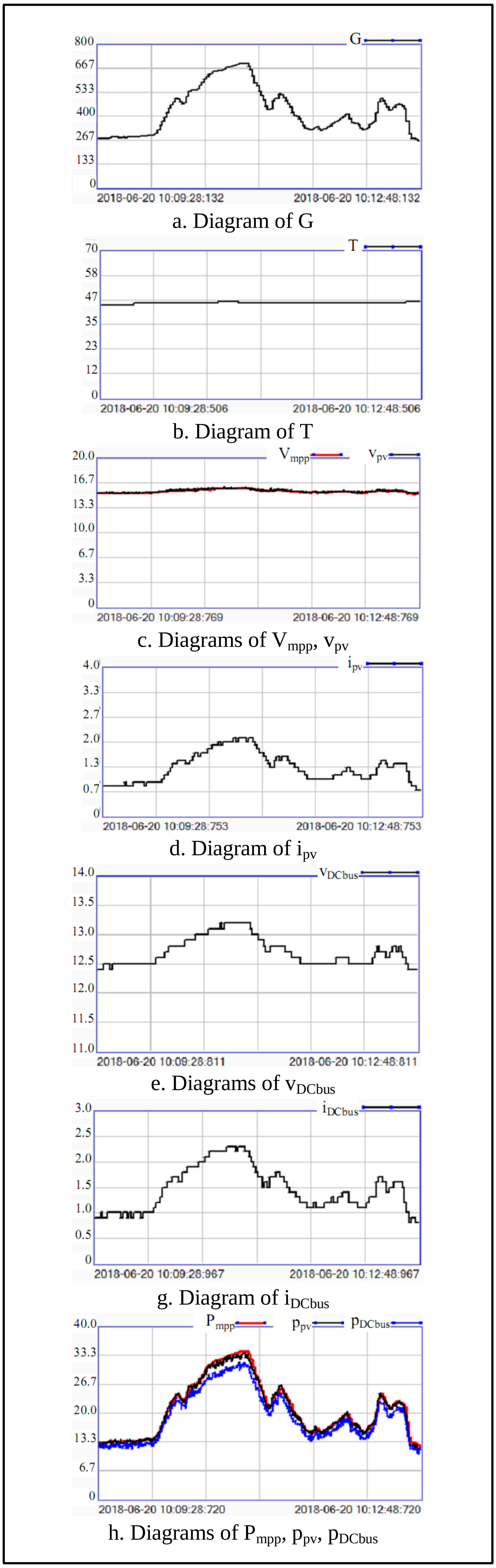
d. Diagram of i_{pv}

e. Diagram of v_{DCbus}

g. Diagram of i_{DCbus}

h. Diagrams of P_{mpp}, p_{pv}, p_{DCbus}

Fig. 8. The first sample



a. Diagram of G

b. Diagram of T

c. Diagrams of V_{mpp}, v_{pv}

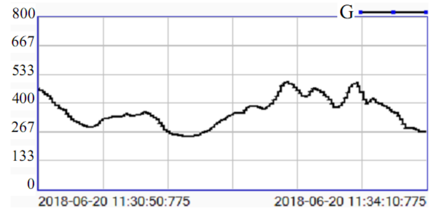
d. Diagram of i_{pv}

e. Diagrams of v_{DCbus}

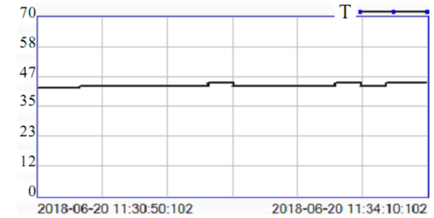
g. Diagram of i_{DCbus}

h. Diagrams of P_{mpp}, p_{pv}, p_{DCbus}

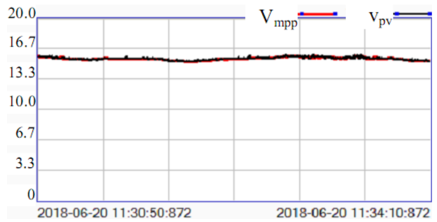
Fig. 9. The second sample



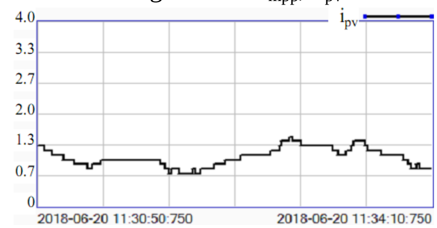
a. Diagram of G



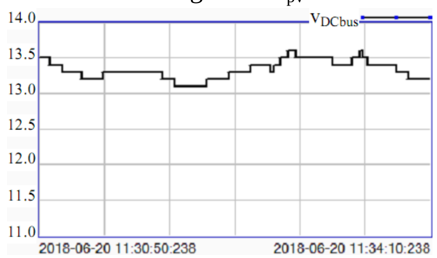
b. Diagram of T



c. Diagrams of V_{mpp}, v_{pv}

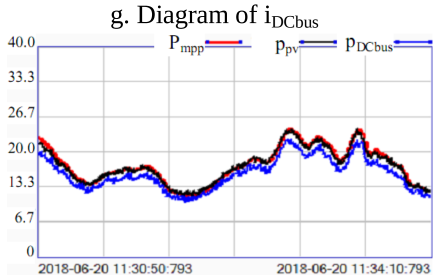


d. Diagram of i_{pv}



e. Diagram of v_{DCbus}

g. Diagram of i_{DCbus}



h. Diagrams of P_{mpp}, p_{pv}, p_{DCbus}

Fig. 10. The third sample

Results in Fig. 8h, Fig. 9h, Fig. 10h show that p_{pv} diagram always coincides with the P_{mpp} diagram and p_{DCbus} diagram is always lower than P_{mpp} diagram a bit but they have the same appearance corresponding to the variation of (G, T). The reasons for this problem are switching loss and power loss caused by conductive units in the DC/DC buck converter. It characterizes for efficiency of the converter and means that the received power is always smaller than harnessed power at the output terminal of PVG.

Experimental results prove that the experimental model is suitable to test the ability to harness all maximum potential power from PVG. They show the high accuracy for the process of extraction, the essence of PVG and the DC/DC buck converter. They also show the ability of high feasibility and efficiency when this structure is applied in system having large capacity.

V. CONCLUSION

This paper proposes a method to harness all maximum power from PVG basing on the completely mathematical model of PVG. This method collects all information about parameters of used PVG (provided by manufacturer or calculated by mathematical tools), system of equations converting value of parameters from STC to any working condition and measured information about working state of whole system.

A control strategy to harness all maximum power from PVG is proposed, where the IB technique combines the completely mathematical model and IB technique in MPPT to accurately calculate parameters at MPP and timely provide desired value for the voltage controller.

An experimental model is introduced and the control strategy for the experimental system is proposed in this paper. Experimental results are shown in three samples to see the role of MPPT and controller in this model. The controller always tracks accurately and fast corresponding to the variation of (G, T) and makes p_{pv} track P_{mpp} accurately at any time. The coincidence of measured quantities and calculated quantities shows the accuracy of choosing type and location to install of sensors to measure (G, T) and the accuracy of the completely mathematical model of PVG and the IB technique in MPPT.

The success of the experimental model shows the feasibility of the proposed structure in real operation with many different capacities. To use the proposed method, panels of PVG must be installed in the same direction, work in unshaded or uncorrupted cells and particularly design controller for each structure of PVG. It shouldn't be design one controller for large scale because the accuracy of this method depends much on measured quantities and surrounding factors that can affect to the working mode of

PVG such as clouds shading panels or difference of temperature on panels. In the future research, this method can be applied in problem of demand-side management for hybrid systems.

VI. ACKNOWLEDGEMENT

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VII. DECLARATION

Authors have disclosed no conflicts of interests.

REFERENCE

[1] Le Tien Phong (2018), "A Study on Methods to improve efficiency of the exaction process for photovoltaic power generation", Dissertation for the degree Doctor of Philosophy on Control Engineering and Automation, Thai Nguyen University of Technology.

[2] Le Tien Phong, Ngo Duc Minh, Nguyen Van Lien (2017), "Improving Efficiency and Response of Photovoltaic Power Generation with DC/DC Buck Converter", International Journal of Engineering Research and Technology, ISSN: 2278-0181, Vol. 6, Issue 3.

[3] Ali Reza Reisi, Mohammad Hassan Moradi, Shahriar Jamasb (2013), "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review", Renewable and Sustainable Energy Reviews, ISSN: 1364:0321, Vol. 19.

[4] Pawan D. Kale, D.S. Chaudhari (2013), "A Review on Maximum Power Point Tracking (MPPT) Controlling Methods for A Photovoltaic System", International Journal of Emerging Science and Engineering, ISSN: 2319–6378, Volume. 1, Issue. 5.

[5] Jiyong Li, Honghua Wang (2009), Maximum Power Point Tracking of Photovoltaic Generation Based on the Optimal Gradient Method, International Conference IEEE ComManTel 2015 placed in Da Nang Province and IEEE Xplore, ISSN: 2157-4847.

[6] Hisham Mahmood, Dennis Michaelson, and Jin Jiang (2012), "Control Strategy for a Standalone PV/Battery Hybrid System", IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society, ISSN: 1553-572X.

[7] Nabil Karami (2013), "Control of a Hybrid System Based PEMFC and Photovoltaic Panels", Dissertation for the degree Doctor of Philosophy, Aix-Marseille University.

[8] Teresa Orłowska-Kowalska, Frede Blaabjerg, José Rodríguez (2014), "Advanced and Intelligent Control in Power Electronics and Drives", Springer Publisher, Volume 531, ISBN 978-3-319-03401-0.

[9] Vernier (2013), http://www.vernier.cz/katalog/manualy/en/pyr-bta.pdf

[10] Texas Instrument (2013), "LM35 Precision Centigrade Temperature Sensors", http://www.farnell.com/datasheets/1848945.pdf.